Inflow and Hydrology

Trends in Freshwater Inflows to Galveston Bay

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Background

The health of Galveston Bay is largely defined by the volume, timing, and quality of freshwater inflows into the bay from surrounding drainage basins. From 1941 to 1987, freshwater inflows to Galveston Bay, defined here as the sum of terrestrial inflows into Galveston Bay, Trinity Bay, East Bay, and West Bay, averaged roughly 10.1 million acre-feet (ac-ft) per year. Of all the contributing basins, the Trinity River basin by far contributes the largest volume of freshwater (54%) to Galveston Bay, followed by the San Jacinto River basin (28%), the San Jacinto-Brazos coastal basin (10%), the Neches-Trinity coastal basin (6%), and finally the Trinity-San Jacinto coastal basin (2%).

The seasonal inflow distribution for Galveston Bay is typified by peak springtime inflows in May followed by minimum inflows in August, as shown in Figure 1. Seasonal inflow distributions for the Trinity River basin, the San Jacinto River basin, and the surrounding coastal basins are distinct from one another (Figure 2), with the seasonal distributions for the San Jacinto River basin and for the coastal basins exhibiting significantly less seasonal variability than shown by the Trinity River. Clearly, the seasonal distribution for total freshwater inflows to Galveston Bay is most influenced by that of the Trinity River.

Perhaps the most significant question asked regarding freshwater inflows to Galveston Bay is whether terrestrial inflows into the bay are on-average increasing or decreasing. As the population within the contributing and surrounding drainage basins which drain into Galveston Bay has increased, the demand for freshwater by municipal, industrial, agricultural, mining, and livestock needs has grown. Inasmuch as these demands represent at least partially consumptive uses of water, the expectation might be for the volume of water reaching Galveston Bay to decrease. However, several factors may act to offset the increased consumption of freshwater, including conservation practices, increases in runoff associated with increased impervious cover due to urbanization, increased use of ground water, and inter-basin importation of water.

Trend Analysis

To test for changes in freshwater inflows to Galveston Bay, a trend analysis was applied to the time series representing total monthly freshwater inflows to the bay. In addition, the analysis was also applied to streamflow time series recorded at

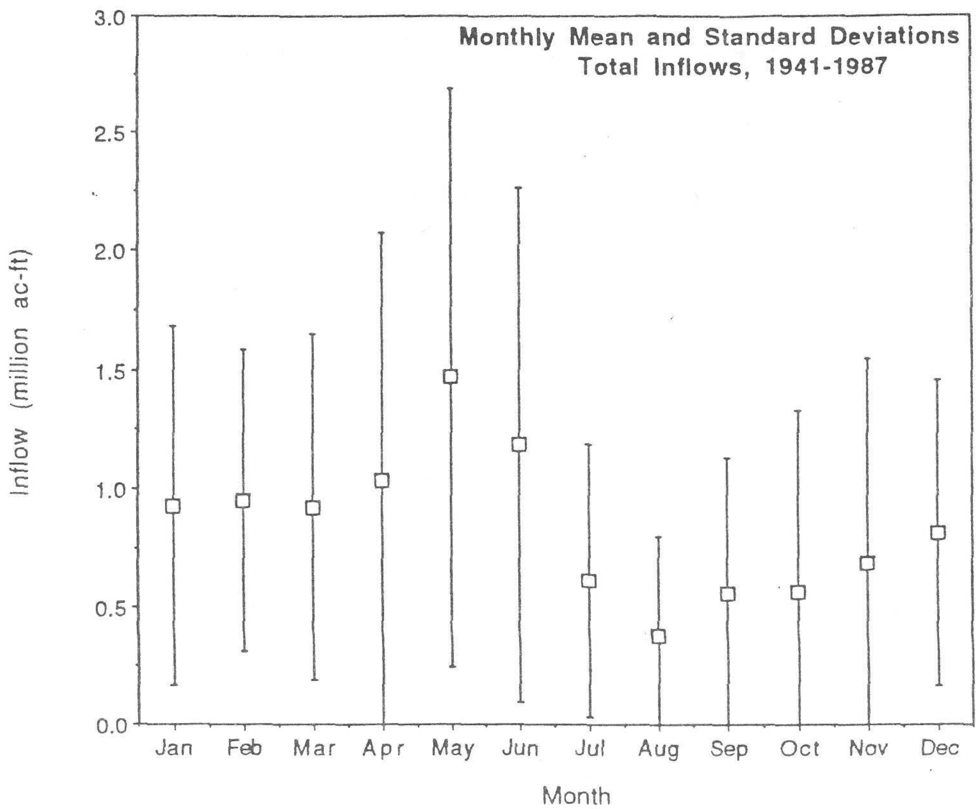


Figure 1. Monthly mean and standard deviation of total freshwater inflows to Galveston Bay, 1941-1987.

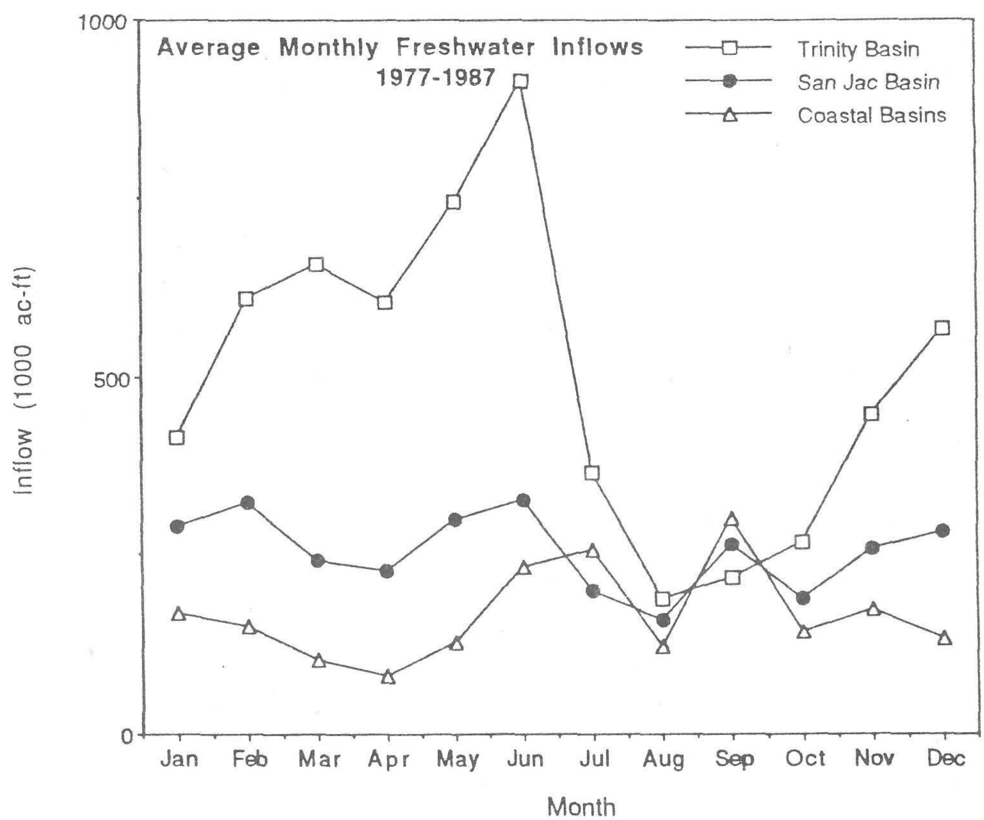


Figure 2. Seasonal freshwater inflow distributions by basin, 1977-1987.

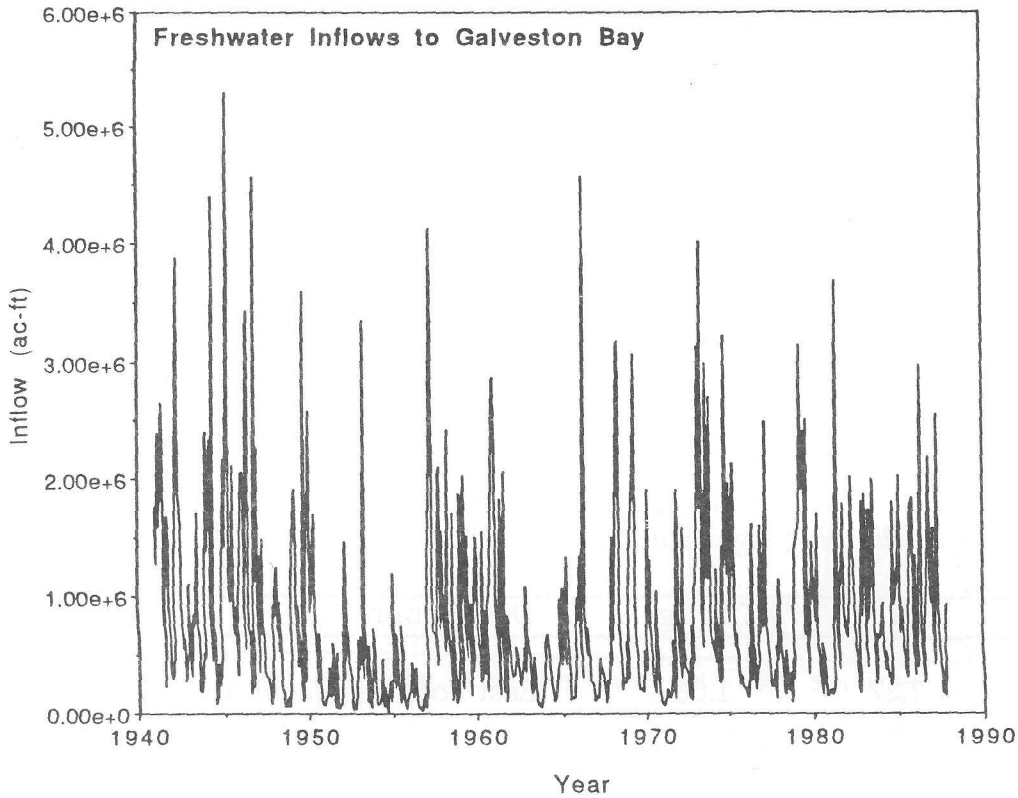
several United States Geological Survey (USGS) stations lying within the Galveston Bay drainage basin. The trend analysis is referred to as the Sen test, and was proposed by Farrell (1980) and Sen (1968) and described by Van Belle and Hughes (1984).

Those time series which showed statistically significant trends ($|t| > 1.96$) over the period from 1968 to 1987 are presented in Table 1 below. The period selected for the analysis purposefully skirts the historical droughts of the 1950s and 1960s in an attempt to key strictly on other influences that might alter freshwater inflow volumes. Surprisingly, neither the time series for overall freshwater inflows to Galveston Bay ($t = 1.41$) nor the time series for the Trinity River gage at Romayor, USGS #8077500 ($t = 0.67$) contain statistically significant trends. However, time series for seven USGS gages showed statistically significant increases in streamflow.

Table 1. USGS gages showing significant trends , 1968-1987.

USGS #	t	% Change	Description
8070000	2.27	1.06	East Fork San Jacinto near Cleveland
8070500	2.19	2.17	Caney Creek near Splendora
8074500	4.62	3.06	Whiteoak Bayou at Houston
8075000	5.29	3.08	Brays Bayou at Houston
8075500	3.58	1.92	Sims Bayou at Houston
8076000	4.77	3.02	Greens Bayou near Houston
8068520	2.19	1.45	Spring Creek near Westfield

The absence of trends in overall freshwater inflows to Galveston Bay and in the Trinity River time series, and the presence of increasing trends in the Brays Bayou and Whiteoak Bayou time series, are clearly evident in Figures 3, 4, 5, and 6, respectively. Both monthly hydrographs and cumulative monthly hydrographs, i.e., the running sum of monthly inflows, are presented in these figures. Note especially, the increasing base flow component in the monthly hydrographs beginning in the 1960s for Brays Bayou and Whiteoak Bayou (Figures 5 and 6). The concave upward shape of the cumulative inflow hydrographs following the 1960s for these two records also support the results of the trend analysis. By comparison, neither the total freshwater inflows to Galveston Bay nor the streamflows on the Trinity River (Figures 3 and 4) exhibit increases in baseflow in the monthly hydrograph nor a concave upward curvature in cumulative inflow hydrograph.



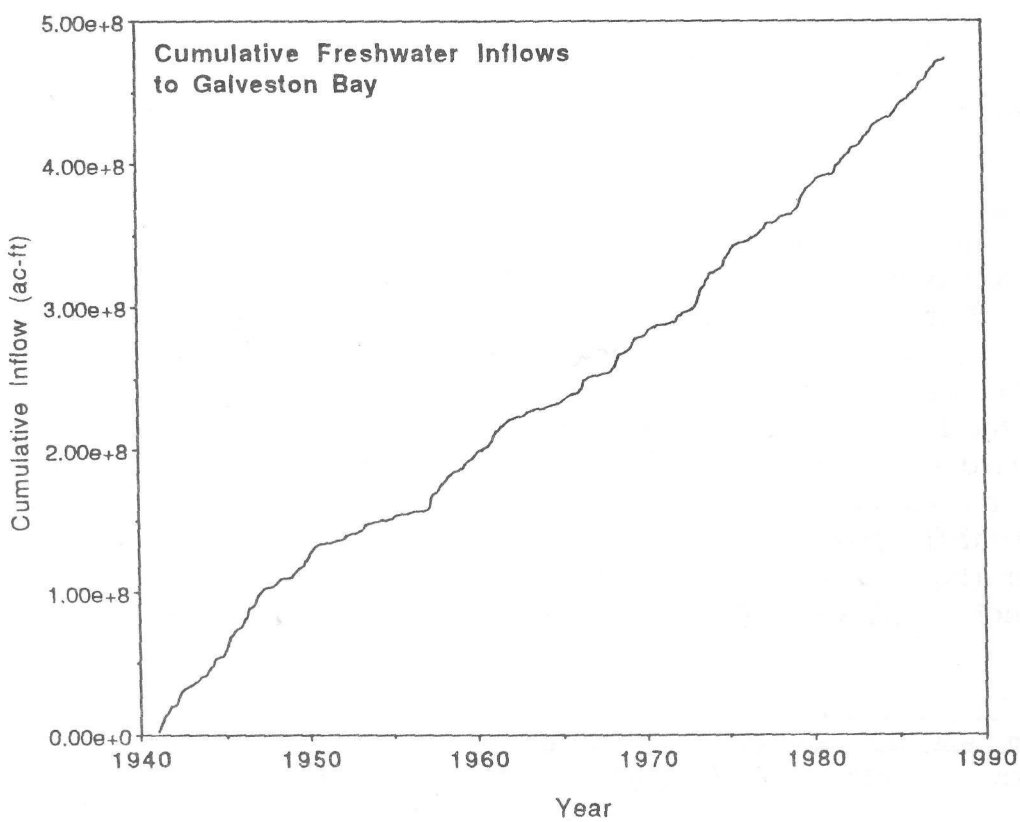
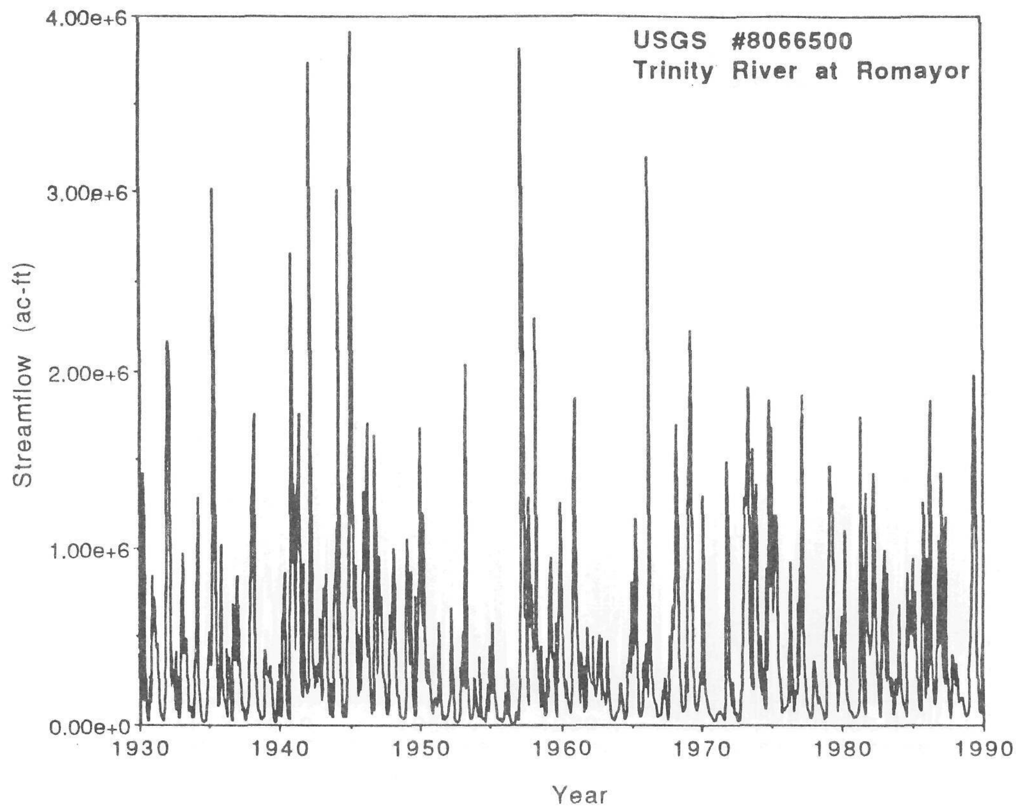


Figure 3. Monthly hydrographs and cumulative monthly hydrographs for total freshwater inflows to Galveston Bay.



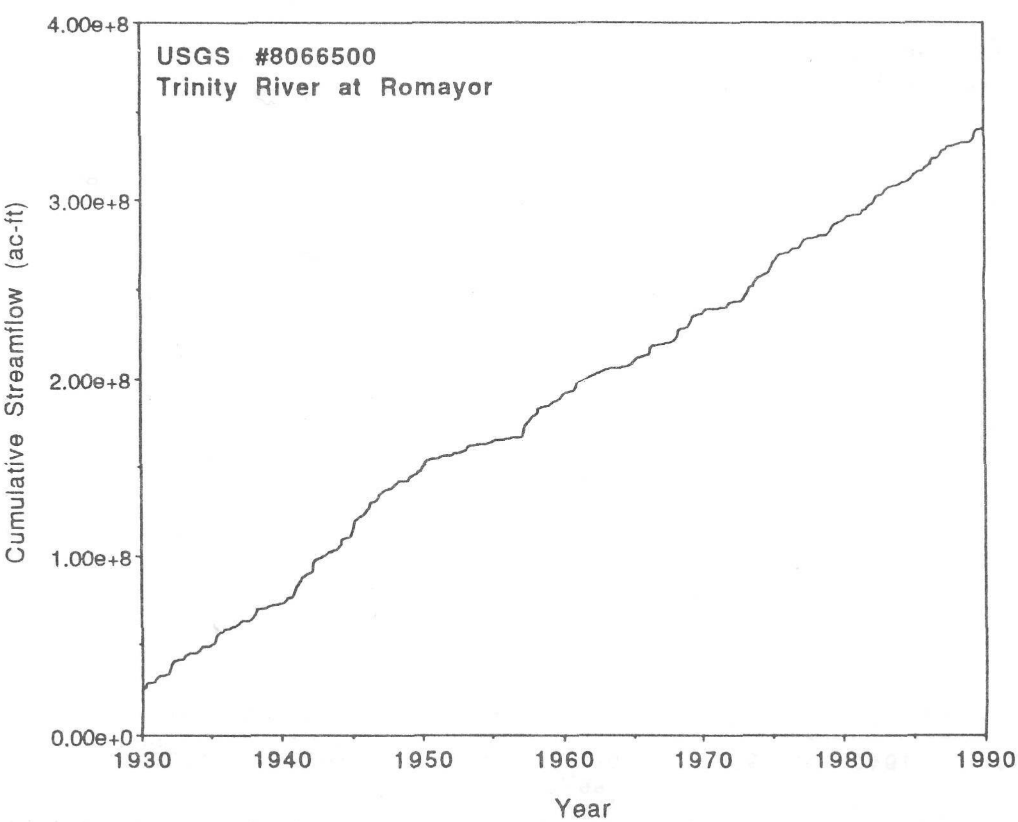
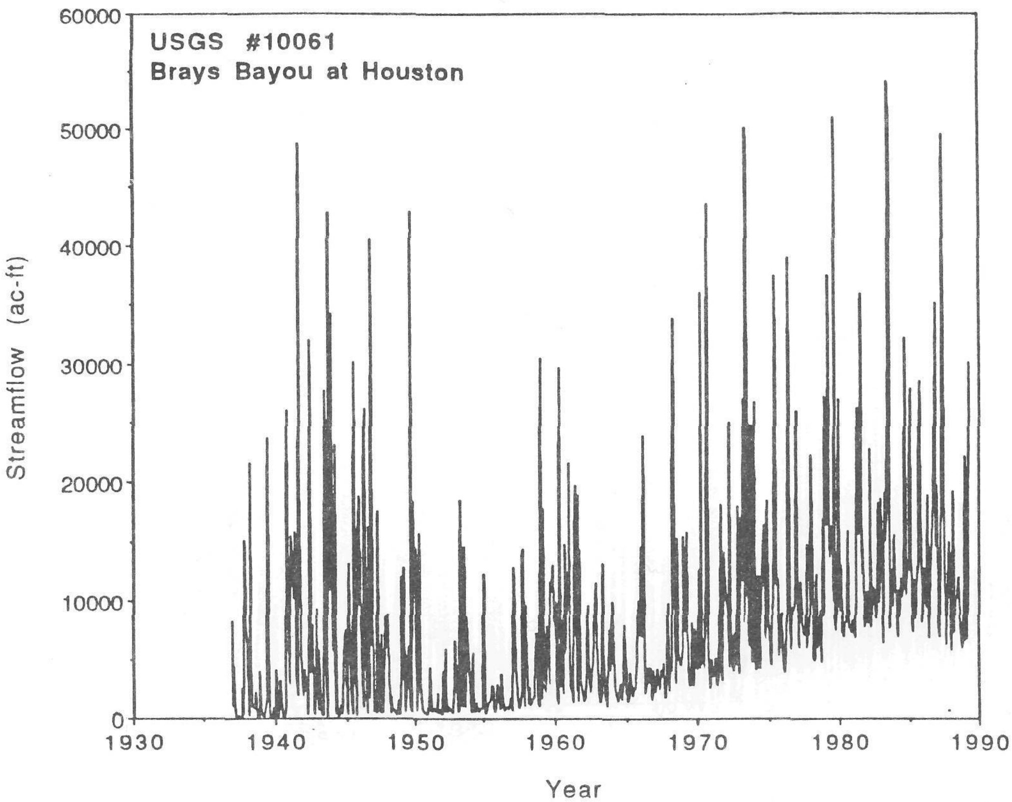


Figure 4. Monthly hydrographs and cumulative monthly hydrographs for streamflow on the Trinity River at Romayor.



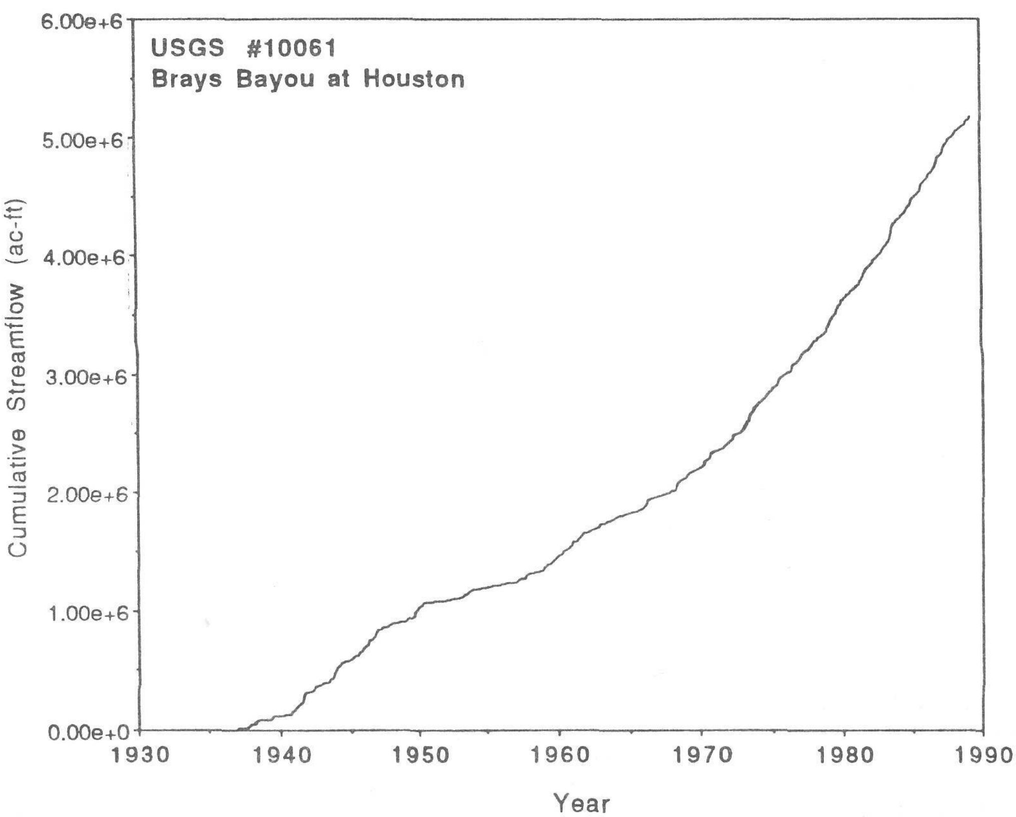
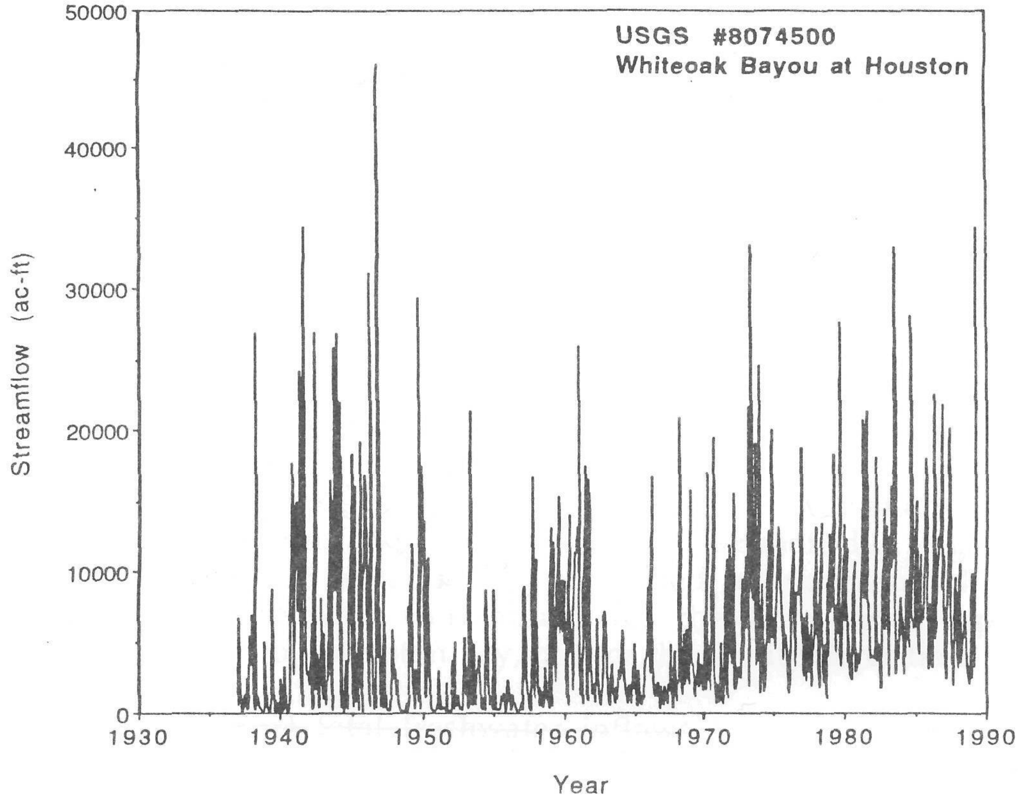


Figure 5. Monthly hydrographs and cumulative monthly hydrographs for streamflow on Brays Bayou at Houston.



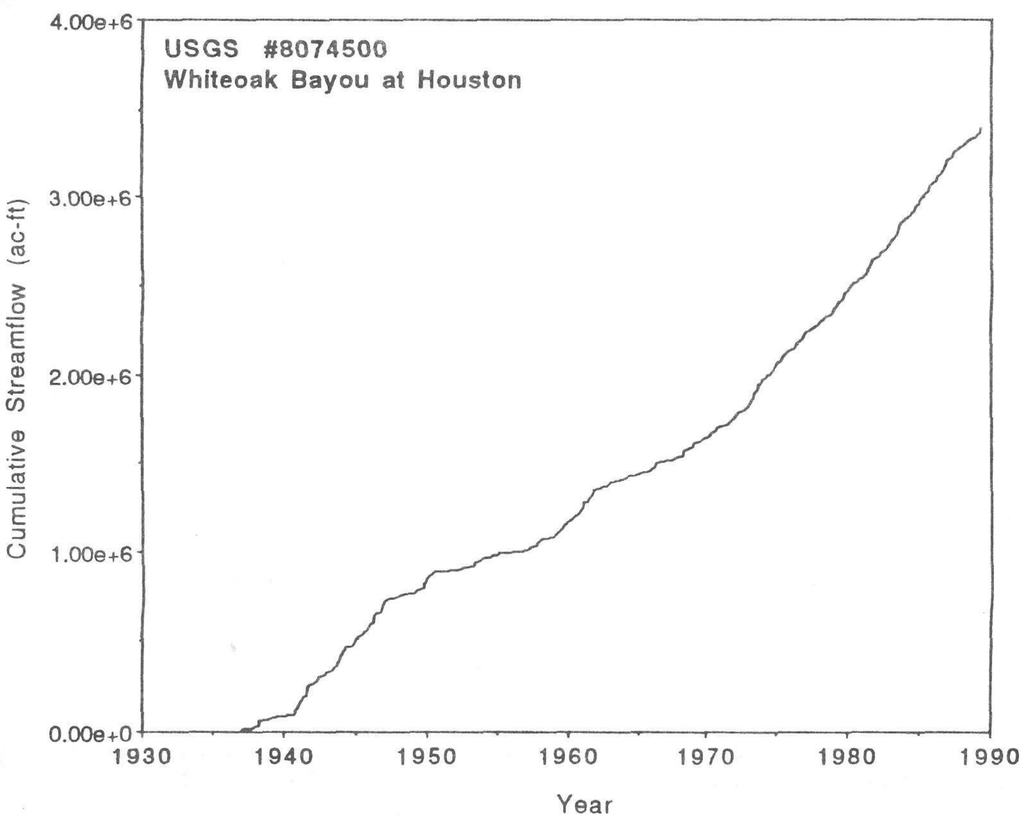


Figure 6. Monthly hydrographs and cumulative monthly hydrographs for streamflow on Whiteoak Bayou at Houston.

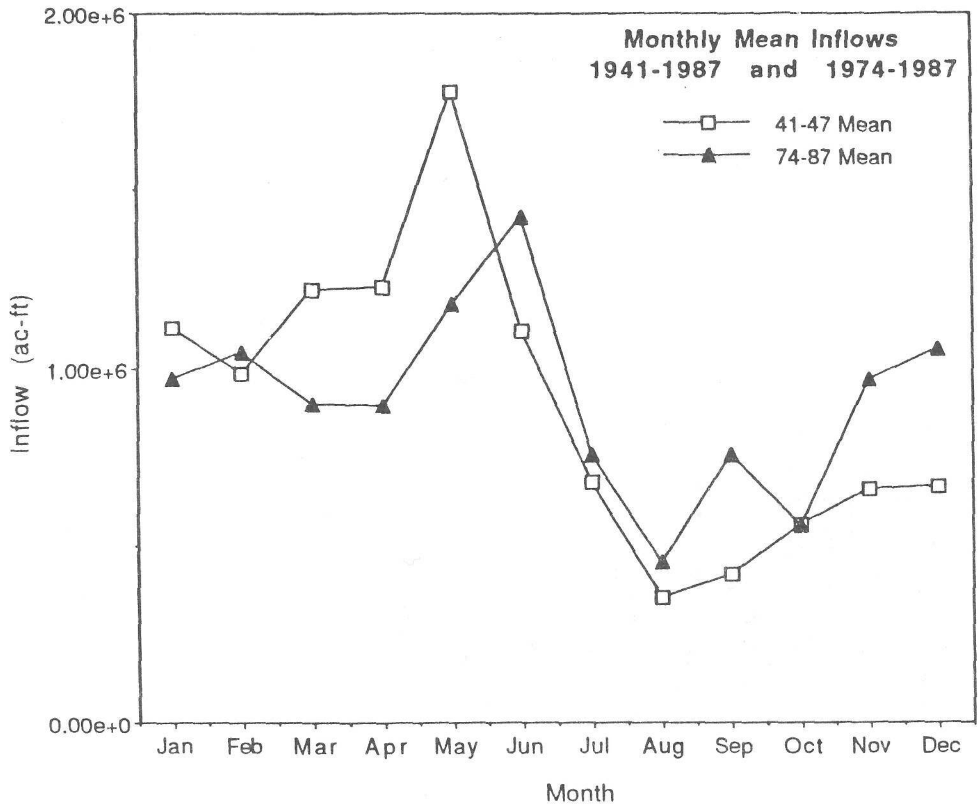


Figure 7. Seasonal distributions for total freshwater inflows from 1941-1954, and from 1974-1987.

Seasonality of Inflows

The seasonal variation in freshwater inflows have apparently remained nearly constant, despite the construction of major reservoirs within the contributing basins. A comparison of average monthly inflows from 1941 to 1954, before impoundment of Lake Houston, Lake Livingston, and Lake Conroe, with monthly inflows from 1974 to 1987, after the reservoirs were completed and in operation, showed no statistical differences (Figure 7).

Summary

Several USGS gages in the Galveston Bay drainage basin have shown increasing streamflow trends from 1968 to 1987. These trends may be attributable to a variety of reasons, including reduced consumptive use due to conservation practices, increases in ground water return flows, increases in surface runoff due to greater impervious cover, and import of water across watershed boundaries. No inflow trends, increasing or decreasing, were found for the time series representing total freshwater inflows to Galveston Bay, nor for the Trinity River time series.

The assumption that total freshwater inflows to Galveston Bay are decreasing cannot be supported. Indeed, if plans to import more water into the Trinity River Basin (TWDB, 1990), primarily to support the municipal needs of Dallas and Fort Worth, reach fruition, increases in total freshwater inflow might occur. Imports to the basin are projected to increase from nearly 340,000 ac-ft in the year 2000 to 640,000 ac-ft in the year 2040.

Finally, no statistically significant changes in the seasonal distribution of freshwater inflows to Galveston Bay were found, although this too could change in the future with increasing inter-basin imports and exports.

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Flow from the Trinity River to Galveston Bay

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The flow of the Trinity River into Galveston Bay varies naturally over a very wide range. Naturalized flows, which remove man-made influences from measured flows by subtracting the effects of reservoir evaporation and storage, diversions, inter-basin transfers, return flows, and run-off rates due to land uses, have been calculated for the Trinity basin by several parties. These are reviewed and compared as they relate to Galveston Bay. The analyses cover the period from the 1940s to the 1970s and 1980s on a monthly basis.

In the Trinity Basin all the above man-made influences are present. Evaporation, diversions, interbasin transfers, and return flows are summarized separately and their effects discussed. Combined with natural flows, a total picture of the sources and fates of water in the Trinity Basin is compiled.

Particular attention is given to low flow conditions, when the greatest need and competition for water occurs. Return flows, particularly, increase the low flows over what they would be naturally, and they have steadily increased over the years. Along the main stem and some tributaries, low flows are now several times the natural flows. There is extensive reuse of return flows in the Trinity Basin and more is planned. Reuse and its impact on low flows is quantified and discussed.

Table 1. Segments of the Trinity River where toxic chemicals and heavy metals have been reported.

Segment	Water Column	Fish Tissue	Sediment
804 Trinity Above Livingston	X	X	X
805 Upper Trinity	X	X	X
806 W. Fork Below Lake Worth	X	X	X
807 Lake Worth			X
812 W. Fork Above Bridgeport Resv.			X
819 E. Fork Trinity		X	
820 Lake Rake Hubbard	X		
823 Lewisville Lake	X		
828 Lake Arlington	X	X	X
829 Clear Fork Below Benbrook Lake	X	X	
831 Clear Fork Below Lake Weatherford	X		
841 W. Fork Above Elm Fork	X	X	

The quality of water in the Trinity River below the Dallas-Fort Worth area has been a major concern for decades. The condition of that part of the river is reviewed using, among other sources, the recent Assessment of Water Quality for the Trinity River Basin prepared under the new Clean Rivers Act in cooperation with the Texas Water Commission. Included in the assessment and in this paper are summary data on the quality of the river below Lake Livingston and entering the estuary.

The Trinity River has many sources and cycles within its watershed, and it has wide variations in flow. Its flow is dominated by natural factors, modified marginally by human activity. Water quality has improved greatly in recent years. Major issues involving the Trinity River in the next few years include non-point source pollution, bay and estuary inflows, and re-use of return flows.

Table 2. Segments of the Trinity River where nonpoint sources of pollution have been reported

Segment	D.O.	Coliforms	Nutrients	Toxics	Solids
801 Trinity River Tidal	X	X	X		
802 Trinity Below Lake Livingston		X	X		
803 Lake Livingstone		X	X		
804 Trinity Above Lake Livingstone	X	X		X	X
805 Upper Trinity	X	X	X	X	
806 W. Fork Below Lake Worth	X	X		X	
807 Lake Worth		X		X	
808 W. Fork Below Eagle Mtn. Lake	X				
810 W. Fork Below Bridgeport Reservoir	X	X			
812 W. Fork Above Bridgeport Reservoir	X	X	X		
814 Chambers Creek		X			
816 Lake Waxahachie	X				
817 Navarro Mills Lake	X				
819 E. Fork Trinity	X	X	X	X	
820 Lake Ray Hubbard		X	X	X	
822 Elm Fork Below Lewisville Lake	X	X			
823 Lewisville Lake				X	
824 Elm Fork Above Ray Roberts Lake	X	X	X		
825 Denton Creek		X	X		
826 Grapevine Lake	X		X		
827 White Rock Lake	X				
828 Lake Arlington				X	
829 Clear Fork Below Benbrook Lake		X		X	
831 Clear Fork Below Lake Weatherford	X	X	X	X	
832 Lake Weatherford		X	X		X
833 Clear Fork Above Lake Weatherford		X			
834 Lake Amon G. Carter	X				
840 Ray Roberts Lake		X			
841 W. Fork Above Elm Fork		X	X	X	

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Water for Texas: The Trans-Texas Water Program

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Introduction

Background — The 1992 update of the Texas Water Plan projected population growth and identified water supply needs into the 21st Century. Substantial immediate needs exist in areas supplied by the San Jacinto River Authority and in south-central Texas, particularly in the Corpus Christi and San Antonio regions. Long-term needs are projected for the Houston metropolitan area. In an effort to address water supply concerns of these major growth centers, the Texas Water Development Board (the Board) has initiated the Trans-Texas Water Program.

Goals and Objectives — The principal objective of the Trans-Texas Water Program is to manage the state's water resources to meet the needs of anticipated economic development in southeast and south-central Texas in an environmentally sound manner.

The 1992 update of the Texas Water Plan identifies Toledo Bend reservoir, with an annual firm yield of over 2,000,000 acre-feet, half of which is the Texas share, as one of the largest single water supply sources available to the State of Texas. The goal of the Trans-Texas Water Program is to evaluate utilization of this resource as part of an overall plan to meet present and future needs throughout southeast and south-central Texas.

Since completion of the 1992 update of the Texas Water Plan, the future potential need for interbasin transfers of available surface water resources has become even more acute, especially for Corpus Christi and San Antonio, as a result of issues related to the Edwards Aquifer and the needs for instream flows and for bays and estuaries.

General Approach — Two geographic planning areas have been identified for study:

1. The Southeast Texas area, which will consider water supply system transfers to address near and long-term needs throughout southeast and south-central Texas, and
2. The South-Central Texas area, which will consider water needs as far west as the San Antonio and Corpus Christi regions.

The water supply and conveyance facilities and institutional and governmental actions for both of the geographic areas, taken as a whole, comprise the Trans-Texas

Water Program.

Initial activities required for the Trans-Texas Water Program encompass a broad range of issues and disciplines. Investigation and resolution of engineering, environmental, regulatory, legal, institutional, and financial matters will be required. Five distinct phases for implementation of the Program have been established. All appropriate issues are to be addressed in each phase of the Program; however, the level of detail and focus will increase as the Program progresses through each phase. Throughout all phases of the Program, there will be strong emphasis on public/agency participation, environmental considerations, and careful evaluation of costs.

Organization and Management

The Board, as the Program Sponsor, will coordinate all planning and management activities and will ensure the ultimate integration of all work efforts into the Program. The Board will also serve as the primary resource to facilitate the Program by supplying technical data, input of staff experts, and entering into agreements with regional sponsors for the two Program geographic areas.

Committee Structure — The eventual success of the Program is dependent on establishing a suitable organizational structure and communication arrangement which will allow maximum participation of all affected parties. The primary mechanism to provide participation in this Program is through the use of a hierarchy of management and advisory committees.

Policy Management Committee — The purpose of the Policy Management Committee is to oversee and coordinate efforts to identify potential interbasin transfers of water to major demand centers, evaluate costs, environmental impacts, and institutional restrictions and develop recommendations for State Water Plan revisions. This committee will review the planning parameters and the topics to be studied, as well as the criteria by which the topics will be measured.

The Policy Management Committee will exist as three distinct entities, as follows:

1. Southeast Policy Management Committee will manage and coordinate activities of the Southeast Water Program and will meet as necessary to review progress and provide direction. Composition will be representatives of the Board, Texas Water Commission, Texas Parks and Wildlife Department, and Southeast Program sponsors;

2. South-Central Policy Management Committee will manage and coordinate activities of the South-Central Water Program and will meet as necessary to review progress and provide

direction. Composition will be the same State Agency members from the Southeast Committee, plus representatives from the sponsors of the South-Central Program and

3. Trans-Texas Program Policy Management Committee will consist of all members of both the above described Committees and will function to coordinate the two portions of the Program through quarterly meetings.

Technical Advisory Committees — The purpose of the Technical Advisory Committees is to provide technical and environmental advice to the respective policy committee.

Program Plan

The purpose of the Program Plan is to establish a framework for organizing the overall effort. The Plan serves as guidance for establishing detailed work plans for each of the two geographic areas. Major Program phases include:

- Phase I — Project Initiation/Conceptual Planning
- Phase II — Project Feasibility Studies
- Phase III — Preliminary Design/State and Federal Permitting
- Phase IV — Property Acquisition/Final Design
- Phase V — Project Construction, Start-Up, and Operation Schedule

The Program Plan is designed to allow activity to proceed concurrently and independently to the maximum extent possible for each of the two geographic areas, Southeast and South-Central. Common study elements will be coordinated by the Policy Management Committee so as to avoid conflicts and inefficiencies. Key milestone periods are established to meld activities of each work group into an overall cohesive program.

Phase I — Project Initiation/Conceptual Planning — The initial phase of the Program Plan will establish proposed committees and provide conceptual development of a water supply plan for the study area. This includes identification of potential interbasin transfers to supply known demand centers, and evaluation of general engineering, environmental, financial, and institutional issues. Reasonably possible options will be investigated for schematic route corridors and terminal storage sites. Alternative conveyance plans will be recommended for inclusion in Phase II and a report summarizing the study activities and conclusions will be developed for review and adoption by the project sponsors.

For the Southeast study area, alternative conceptual plans will have been developed as a result of previous investigations conducted by the City of Houston, Sabine River Authority, and San Jacinto River Authority. Many conveyance routes have been studied and cost estimates developed for the transfer of Trinity, Neches, and Sabine waters. To document and update the previous studies, a conceptual plan will be developed for the Southeast area and provided for early review and evaluation for program participants.

For the South-Central area, the conceptual planning studies will require compilation of previously completed water supply planning documents. Additionally, effort will be needed to assess conceptual routes for regional conveyance facilities, terminal storage sites, and other supply options.
Some of the important issues to be identified during this phase include the following:

- Goals, objectives, and concerns of Program participants;
- General service area/water customers for the raw water to be supplied by the facilities;
- Availability and water rights associated with surface waters available to meet the projected demands; and
- Potential routes, terminal storage sites, component sizing, and phasing options to achieve the needed interbasin transfers.

Phase II — Project Feasibility Studies — This Program phase is designed to investigate the engineering, environmental, and institutional components of various supply alternatives in more detail. A primary component of this phase is completion of an environmental analysis, which will be used as a basis to request Texas Water Commission water rights permit amendments. The environmental analysis will evaluate the engineering and environmental impacts of various supply and conveyance alternatives. Preferred routes that are the most viable alternatives will be further identified and investigated.

This phase culminates in the development of a Preliminary Implementation Plan. The goal of that plan is to provide an initial schedule and comprehensive list of activities for the remainder of the project and to establish costs and legal/institutional issues with enough detail to allow "go/no-go" decisions by Program participants.

Some of the important issues to be identified during this phase include the following:

- Treatability and water quality concerns of the available supply;
- Environmental issues and impacts associated with the conveyance alternatives and with the overall Program;

- Advantages and disadvantages of using existing available facilities;
- Initial construction and operational cost estimates;
- Debt financing and pricing alternatives available to the Program participants; and
- Legal/institutional issues.

Phase III — Preliminary Design/State and Federal Permitting — During this phase, a preferred supply plan will be further analyzed and a final alternative selection process will be accomplished. Issues initially identified in Phase II will be thoroughly analyzed during Phase III. A detailed environmental information document (EID) will be completed and submitted to the appropriated federal and/or state agency. Upon approval of the necessary permits, all other remaining institutional/agency contracts can be developed. Finally, a detailed implementation plan will be developed for the entire Program.

Phase IV — Property Acquisition/Final Design — This phase includes two major elements — property acquisition and final design. Property acquisition will include survey and property owner description services, and, if necessary, professional and technical assistance during property negotiations and acquisition. Final design includes survey and geotechnical services, final engineering design, preparation of detailed plans and specifications, and contract documents for construction purposes.

Phase V — Construction, Start-Up, and Operation — This phase consists of assistance during the bid phase and construction management services during the construction phase of the families. Also included are initial start-up and operational services during the first year of service.

Schedule — Implementation of a program of the magnitude of the Trans-Texas Water Program must be considered as a long-range initiative. At this time, a Program schedule has been developed for Phases I and II only. These phases are anticipated to require at least 18 to 24 months. Schedules for subsequent phases will be planned as additional Program elements are developed in more detail.

Financing

Contract Organization — Two principal contracts are proposed for delegating a majority of the planning and implementation efforts to the local level. The Sabine River Authority and Lavaca-Navidad River Authority will be the regional sponsors for the Southeast and South-Central Projects, respectively. In addition, the Brazos River Authority, Lower Colorado River Authority, City of Austin, and City of San Antonio/Edwards Underground Water District will be participating in this study.

Budget — The total estimated budget for Phases I and II is $2.2 million. Since separate studies are proposed for the Southeastern and South-Central areas, the

Program budget is $1.1 million for each of the two study areas. The budget is structured to provide comprehensive coverage of all activities likely to be needed throughout the initial two phases of the Program.

Method — Program funding will be provided through a combination of Board loan agreements and local sponsor contributions. Local funding for the Southeast area will be provided by the City of Houston, the Sabine River Authority, and the San Jacinto River Authority. Local funding for the South-Central area will be provided by the Lavaca-Navidad River Authority and City of Corpus Christi. Provisions exist within the Program to include future funding participants, if appropriate.

Current Project Status

Contracts — Contracts have been executed with the Sabine River Authority and the Lavaca-Navidad River Authority for the Southeast and South-Central study areas. These contracts include subcontracts for engineering with Brown and Root, Inc. (Southeast) and HDR, Inc. (South-Central).

Work Status — The current work underway includes initiation of a channel loss study from Garwood to Lake Texana in the South-Central study area and transfer of TWDB data files to the consultants of population projections and future water demands.

Tidal Monitoring on the Upper Texas Coast

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Introduction

There are many uses for tidal water level data. For example, the TWDB requires such data as input to a mathematical model of the bays and estuaries of the Texas coast to enable the forecasting of freshwater requirements. The TGLO is responsible for all state owned lands and submerged territories in Texas to a distance offshore of 9 nautical miles. Tidal data is necessary to determine the boundary of such submerged waters. NOS is a traditional user of data for predicting tides for navigational purposes and for mean sea level rise. Also, the US Army Corps of Engineers (USACE) requires data for all coastal engineering projects.

In the near future, tidal water level data may be incorporated with meteorological data (such as wind and temperature) to aid navigation safety, hurricane evacuation emergencies, oil spill clean up programs, and weather forecasting. Furthermore, the data is of value to recreational users of the Texas coast, such as fisherman, pleasure boaters, wind surfers, and swimmers.

To meet this demand for tidal information, the TGLO has initiated a coastal environmental monitoring program called the Texas Coastal Observation Network (TCOON). A brief description of the program is given below.

TCOON

The NOS has systematically monitored tidal levels on the Texas coast since the devastating hurricane at Galveston in 1901. Since then, as many as 80 coastal sites have been occupied for differing periods of time. In 1975, NOS designed a modern, GOES Satellite recording tidal level station named the "Next Generation Water Level Measuring System" (NGWLMS, Edwing, 1991). About 250 NGWLMS units were purchased for the United States coast, and about 200 of these are currently deployed. Ten of these units have been installed on the Texas coast by NOS since 1988. (The systems are described below in more detail.)

Over the past 20 years, the TWDB has been monitoring tides in the bays and estuaries of the coast with the ultimate goal of maintaining a suitable salinity for the ecological environment. They used Stevens' float recorders, which are mechanically driven and provide several months of data at one time. The USACE have established many tide staff sites to meet dredging survey and marine construction requirements over the years.

It has long been recognized that insufficient tidal data exists for the Texas coast to meet the requirements of all agencies and interested parties. An initiative was, therefore, undertaken by the TGLO to fund a tide gauge program beginning in 1989. At that time, state funding was acquired to install a tide gauge network on the Lower Texas coast. The Conrad Blucher Surveying Institute of CCSU was contracted to implement the program, and TCOON was established by their effort. In 1991, this funding was extended to the Upper Texas coast, and LU was invited to participate in a $1 million program to expand the network. Since LU had been monitoring tidal and other environmental parameters in the Sabine-Neches Waterway since 1984, this added project required minimum effort for mobilization.

At this date, 20 of the NGWLMS gauges are managed by TCOON. Fifteen of these gauges have been installed by the CCSU between Freeport and Brownsville, and five by LU between Freeport and Texas Point. The present funding allows for three more gauges to be installed on the Upper Texas coast in the near future, thus bringing the TCOON total to 23 gauges. Figure 1 shows the disposition of NGWLMS gauges for the Upper coast, and there totals 11 gauges, namely eight TCOON and three NOS gauges.

A recent survey of the TCOON status by NOS has concluded that at least 34 gauges are required to meet the current demand for tidal information. Together with the 10 NOS gauges, the Texas total would become 44. Of these, 16 TCOON gauges would be located on the Upper coast, and 18 on the Lower Texas coast.

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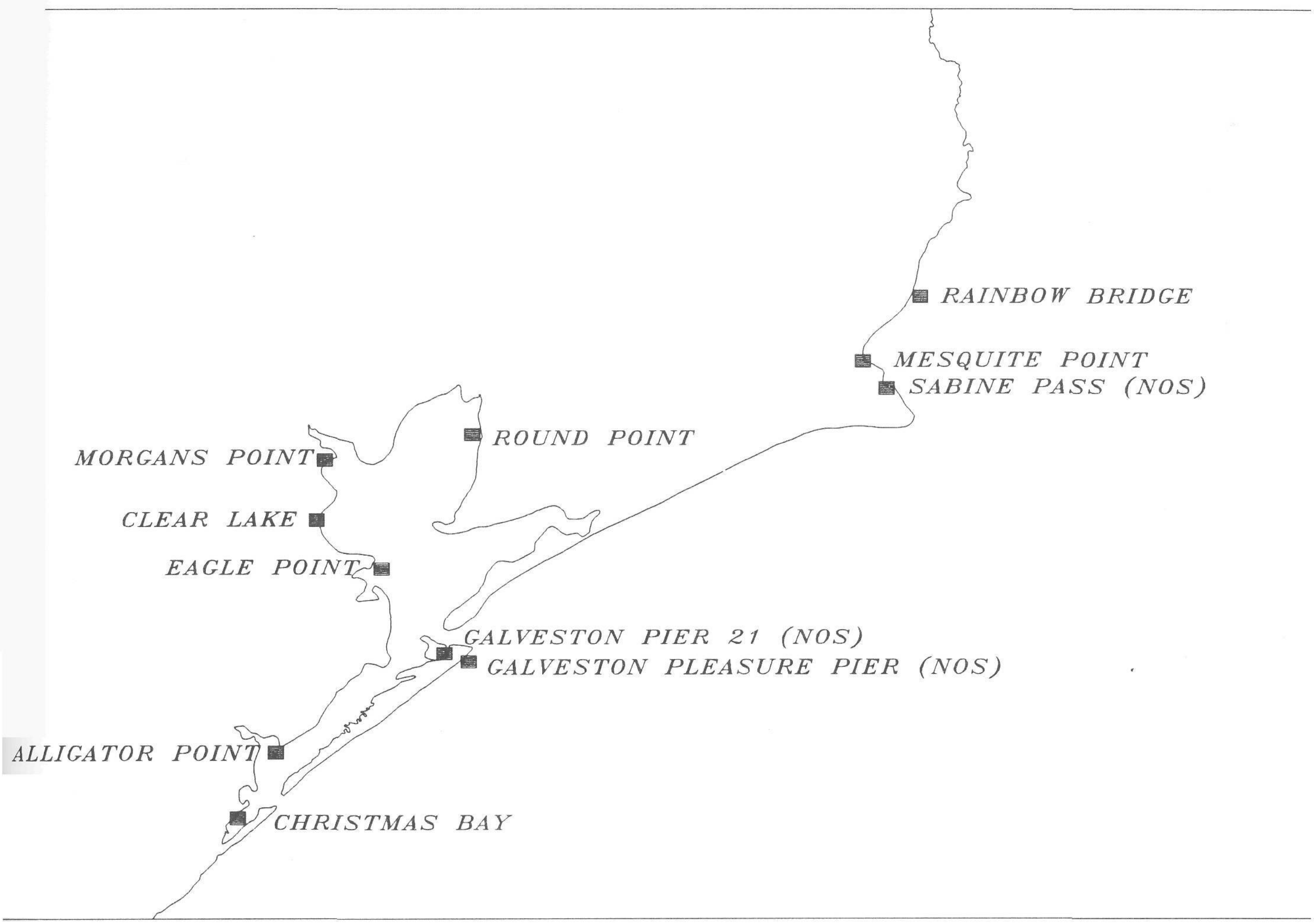

Figure 1. Next generation water level measuring systems along the upper Texas gulf coast.